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Low-temperature and global epitaxy of GaN on amorphous glass substrates by molecular beam epitaxy via a compound buffer layer

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ABSTRACT

GaN epilayers are globally grown on amorphous glass substrates via a compound buffer layer including Ti pre-orienting layer and AlN nucleation layer (NL) grown by molecular beam epitaxy at 530 °C. It is shown that the ratio of V/III during AlN growth plays a key role in the crystallinity of AlN NL as a trade-off between the formation of Al clusters and the mobility of Al adatoms. The N_2 flux has an optimal value of 2.4 sccm when the Al flux is fixed to 7.46×10^{-8} Torr at the RF power of 400 W. The obtained smooth GaN epilayer is hexagonal single-crystalline with the grain size in the order of submicron magnitude and root-mean-square roughness of 2.83 nm, which shows the great potential in the epitaxy of III-nitrides on amorphous glass substrates.

1. Introduction

III-group nitride semiconductor epilayers, e.g. GaN and InGaN, have been widely applied to light emitting diodes (LED) [1–5]. However, most of GaN-based LEDs are grown on single-crystal substrates, such as c-plane sapphire, Si (111) and 6H-SiC [6–12]. It is difficult to realize directly flat panel light sources on these single-crystal substrates as they have relatively high costs and small sizes [13]. The amorphous substrates, such as glass, have large sizes but lack of epitaxial template which provides two-dimensional periodic lattices to match GaN-based epitaxial layers [14]. Hence, a buffer layer, which has the similar epitaxial relationship with III-group nitrides, is necessary for the epitaxy of III-group nitrides on amorphous substrates [15]. Ti film is an appropriate candidate of the buffer layer as hexagonal c-oriented (002) Ti has the same lattice structure as the wurtzite GaN and the theoretical lattice mismatch between them is 7.4%. J.H. Choi et al. fabricated nearly single-crystalline GaN LEDs on glass substrates deposited with a c-oriented Ti film successfully [16–18]. However, the complicated selective area epitaxy including the pattern of micro-holes and the formation of lateral pyramids array was involved as the deposited Ti film had randomly-oriented a-axe in the in-plane direction. Furthermore, the high temperature up to 1040 °C was needed during the epitaxy. Therefore, it is impossible to apply those processes to the float glass substrates as their melting point is generally no more than 600 °C.

J.W. Shon et al. fabricated full-color InGaN-based LED on amorphous substrates by pulsed sputtering via multilayer graphene buffer layer. However, the multilayer graphene layers were grown by chemical vapor deposition on Ni foil and had to be transferred onto amorphous glass substrates, and the growth temperature is up to 760 °C, which is also higher than the melting point of the float glass [19]. In our previous study, c-oriented (002) Ti film was obtained on glass substrates by electron beam (EB) evaporation as a pre-orienting layer (OL) and GaN globally grown on Ti/glass template by plasma-assisted molecular beam epitaxy (PA-MBE) at 530 °C exhibits the same epitaxial relationship to Ti OL [14]. But the resulting GaN is an assembly of randomly a-axes oriented grains, i.e., poly-crystalline film, as the a-axes orientation of Ti film is random. An interlayer which enables the global epitaxy of III-nitrides is necessary to further improve the performance of III-nitrides grown on amorphous glass substrates no more than 600 °C. In this paper, the growth of GaN on amorphous glass substrates via an AlN/Ti compound buffer layer (BL) by PA-MBE at the temperatures of 530 °C is studied, since there are many kinds of cheap non-single-crystalline substrates can bear this temperature. The crystal quality will deteriorate or the non-single-crystalline substrates is at risk of softening (or melting) when the growth temperature is too low or too high. The growth of AlN is optimized to form a single crystalline epitaxial template on a c-oriented (002) Ti film. Then the bulk GaN layer is grown on AlN template and its crystallinity is studied.

2. Experimental details

All the samples were deposited and grown on amorphous glass substrates by an EB and a PA-MBE system. Firstly, a 300-nm-thick Ti

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Table 1
The N_2 flux during the growth of AlN NL as well as the AFM and XRD results of the following GaN epilayers in five samples.

Samples	N_2 flux of AlN NL (sccm)	$10 \times 10\,\mu m^2$ RMS (nm)	(002) FWHM (°)
A	1.0	9.78	7.25
B	1.5	5.05	4.01
C	2.0	3.39	2.53
D	2.4	2.83	1.89
E	3.0	6.26	4.55

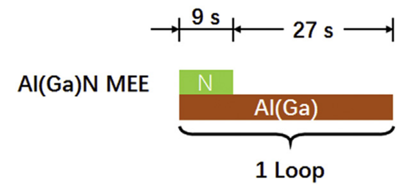

Fig. 1. Schematic diagram MEE growth modes of AlN and GaN.

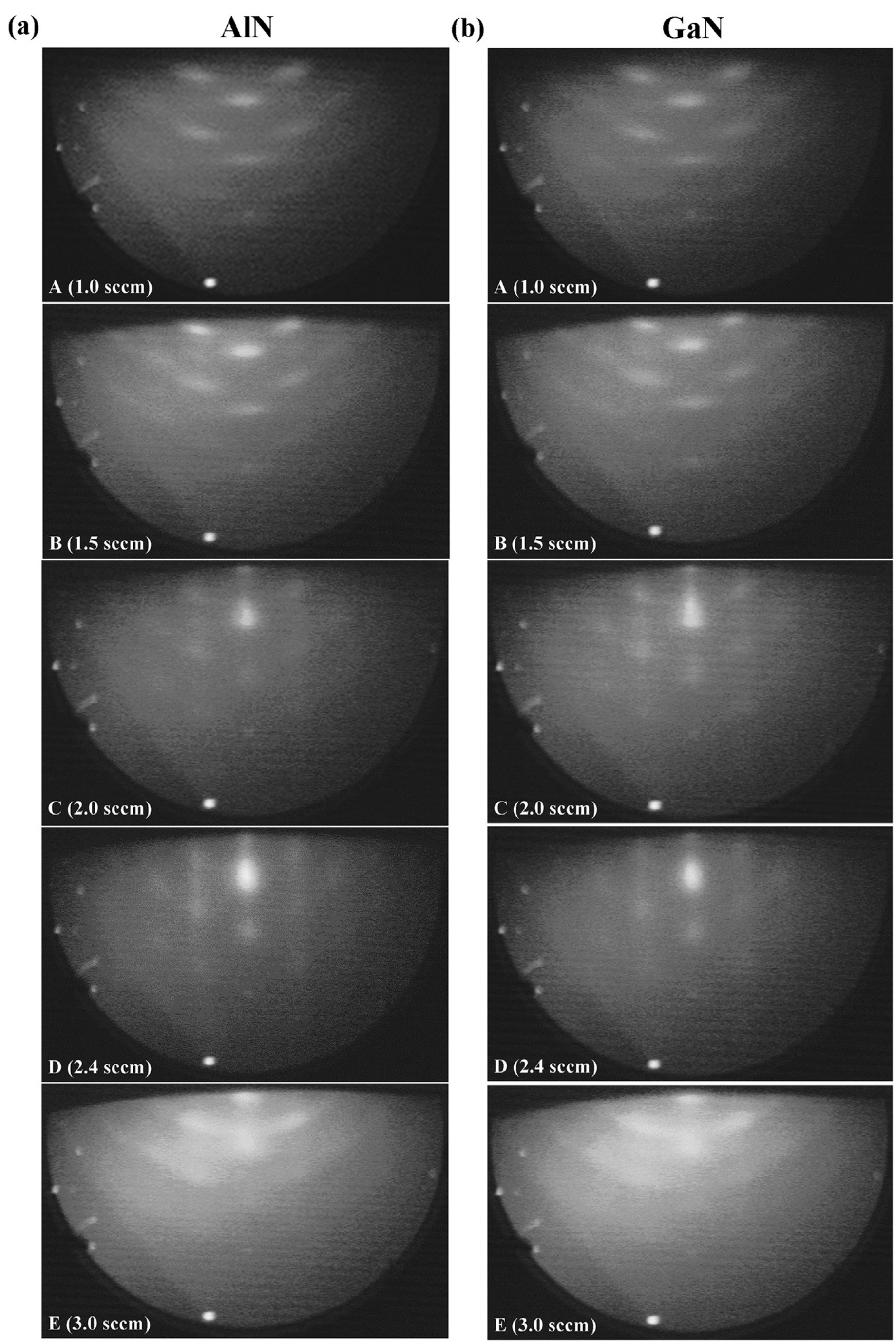

Fig. 2. RHEED patterns of (a) AlN NLs at different N_2 flux on Ti c-orienting layer and (b) the following GaN epilayer grown on AlN/Ti buffer layer. N_2 flux has a key effect on the RHEED patterns of AlN NLs, i.e., the surface crystallinity. All images in (b) are almost as the same as the corresponding images in (a), which means the lattice of GaN epilayer follow the surface template of AlN NLs.